

15. (New) An apparatus according to Claim 9, further comprising correcting means for correcting a change in an illuminance distribution on a surface to be illuminated, resulting from changing an angular distribution of the illumination light with said adjusting means.--

**REMARKS**

Applicant requests favorable reconsideration and allowance of the subject application in view of the preceding amendments and the following remarks.

At this time, Applicant also requests consideration of the Supplemental Information Disclosure Statement filed on March 26, 2001. In this regard, Applicant requests that the Examiner initial and return a copy of the PTO-1449 Form that accompanied that Disclosure Statement, indicating such consideration.

To place the subject application in better form, Applicant submits herewith a substitute specification. Applicant's undersigned attorney has reviewed the substitute specification and asserts that the substitute specification contains no new matter.

Without conceding the propriety of the rejections set forth in the above-noted Office Action and solely to advance prosecution, claims 9-15 are now presented in lieu of claims 1-8, which have been canceled without prejudice or disclaimer. Claim 9 is the sole independent claim.

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Applicant notes that the Examiner has made final the Restriction Requirement previously set forth. Claim 8, withdrawn from consideration, has been canceled without prejudice or disclaimer. Applicant reserves the right to file a divisional application directed to the subject matter of this claim.

Applicant requests favorable reconsideration and withdrawal of the rejections set forth in the above-noted Office Action.

Claims 1-7 were rejected under 35 U.S.C. §112, second paragraph, as being indefinite. The Examiner objected to specific recitations in claims 1 and 4. Claims 1-7 having been canceled, this rejection has become moot and should be withdrawn. Nevertheless, the Examiner's comments were taken into consideration when presenting claims 9-15. Applicant submits that this rejection has been overcome. Such favorable indication is requested.

Turning now to the art rejection, claims 1-7 were rejected under 35 U.S.C. §102 as being anticipated by U.S. Patent No. 5,798,824 to Kudo. Applicant submits that this patent does not teach many features of the present invention, as previously recited in claims 1-8. Therefore, this rejection is respectfully traversed. Nevertheless, claims 9-15 are now presented to amplify the distinctions between the present invention and the cited art.

Independent claim 9 recites a projection exposure apparatus that includes an illumination optical system for illuminating a reticle with light from a light source, a projection optical system for projecting a pattern of the reticle, as illuminated, onto a substrate, measuring means for measuring telecentricity of the projection optical system with respect to different image heights and adjusting means for adjusting an incidence angle, upon the reticle, of illumination light corresponding to each of the different image heights, to correct the telecentricity with respect to a respective image height.

Applicant submits that the cited art does not teach or suggest such features of the present invention, as recited in independent claim 9.

The Kudo patent relates to an illumination optical apparatus capable of correcting unevenness of an illuminance distribution on an illuminated surface, particularly slant unevenness thereof. This patent teaches a measuring device for measuring an illuminance distribution of a projection optical system along an image plane, and an adjusting device for adjusting the incidence angle to correct the illuminance distribution. Applicant submits, however, that the Kudo patent does not teach or suggest any telecentricity measuring means or incidence angle adjusting means, as in the present invention recited in independent claim 9. Therefore, the Kudo patent does not teach or suggest many features of the present invention.

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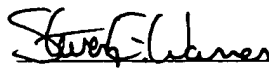
For the foregoing reasons, Applicant submits that the present invention, as recited in independent claim 9, is patentably defined over the cited art.

Dependent claims 10-15 also should be deemed allowable, in their own right, for defining other patentable features of the present invention in addition to those recited in independent claim 9. Individual consideration of these dependent claims is requested.

Applicant submits that the instant application is in condition for allowance. Favorable reconsideration, withdrawal of the rejections set forth in the above-noted Office Action, and an early Notice of Allowance are requested.

Applicant's undersigned attorney may be reached in our Washington, D.C. office by telephone at (202) 530-1010. All correspondence should be directed to our address listed below.

Respectfully submitted,

  
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PROJECTION EXPOSURE APPARATUS AND  
DEVICE MANUFACTURING METHOD USING THE SAME

FIELD OF THE INVENTION AND RELATED ART

5                   This invention relates to a projection  
exposure apparatus and a device manufacturing method  
using the same.

10                   In projection exposure apparatuses for use  
in the manufacture of semiconductor devices, for  
example, higher resolution has been required to meet  
enlargement of integration of VLSI. In this stream,  
ultra-resolution technology using an oblique incidence  
illumination method or a phase shift mask has been  
15                   proposed. In such ultra-resolution technology, the  
aperture stop of an illumination optical system is  
modified to make smaller the  $\sigma$  value (the ratio  
between the NA (numerical aperture) of a projection  
optical system and the NA of the illumination optical  
system), or a secondary light source of a peculiar  
20                   shape such as a ring zone shape or quadrupole shape,  
for example, is defined.

25                   Also, in projection exposure apparatus for  
semiconductor device production, generally the optical  
arrangement is telecentric on the image side so that  
there occurs substantially no deviation of the  
position of a projected pattern image even if a  
substrate such as a wafer is at a defocused position.

In the stream of larger integration of recent VLSI, a very high transfer precision is required for printing of a circuit pattern. It is, therefore, very important to properly set the angular distribution of illumination light, entering a projection optical system. If illumination light with a predetermined angular relation with respect to the projection optical system is not supplied, then a positional deviation occurs in the position of a projected pattern image [in] on an occasion [where] when the wafer is at a defocused position.

When a wafer is defocused and a pattern is printed, a deviation in incidence angle of illumination light in magnification relation with the optical axis center, with respect to a projection optical system (i.e., deviation of incidence angle of each light ray with respect to the projection optical system, according to the distance (object height) to the optical axis), causes a positional deviation in magnification component corresponding to the image height, in the printed pattern. This deviation is referred to as magnification telecentricity or deviation of magnification telecentricity. Figure 2 illustrates this, wherein broken lines denote an optical axis or a line parallel to it.

In Figure 2, denoted at 16 is a projection optical system, and denoted at 18 is a substrate

(wafer). Denoted at La is the optical axis of the projection optical system 16. A shift or deviation of incidence angle of illumination light with respect to the projection optical system, with which chief rays are inclined in the same direction regardless of object height, causes a shift or deviation of a printed pattern when the wafer 18 is defocused (this deviation is referred to as an on-axis telecentricity or deviation of on-axis telecentricity). Figure 3 illustrates this, wherein broken lines denote an optical axis or a line parallel to it.

This means that images are printed with deviation when, during the procedure of plural lithographic processes, circuit patterns are to be superposedly printed on a wafer having surface steps formed thereon. It is very undesirable for production of high precision semiconductor devices.

In many projection exposure apparatuses, positions of components of an illumination system are adjusted so that it provides illumination light with an angular characteristic best for a certain standard illumination mode A. However, when the illumination mode A is changed to a different illumination mode B (such as for oblique incidence illumination or smaller  $\sigma$  value), the components of the illumination system, if they are unchanged as in the illumination mode A, do not always provide illumination light with a proper

angle. This is because the optical path is different between these illumination modes and also the effect of eccentricity of a lens [stem] system or non-uniformness of an anti-reflection film of an optical element differs.

In projection exposure apparatuses, the effect of an anti-reflection film used for an optical element differs with the angle of a light ray. Thus, when the illumination mode is changed, there may occur a deviation of magnification telecentricity. Similarly, when the illumination mode is [change] changed, the effect of reflection non-uniformness at deflection by a mirror or the effect of eccentricity of an optical system changes. Thus, there may occur a deviation of on-axis telecentricity.

If such magnification telecentricity or on-axis telecentricity is corrected by moving the optical system, it causes a change in illuminance distribution on the surface to be illuminated (such as a reticle surface or wafer surface), thus enlarging illuminance non-uniformness. It is not easy to correct both of them in conventional exposure apparatuses.

#### SUMMARY OF THE INVENTION

It is an object of the present invention to provide a projection exposure apparatus by which, based on correction of magnification telecentricity deviation, illumination light can be supplied with an



optimum angle such that a pattern image can be formed with a very high resolution.

It is another object of the present invention to provide a device manufacturing method using such a projection exposure apparatus.

In accordance with an aspect of the present invention, there is provided a projection exposure apparatus having an illumination optical system for illuminating a reticle having a pattern, a projection optical system for projecting the pattern onto a substrate, and measuring means for measuring an angular distribution of illumination light, wherein an optical element in a portion of said illumination optical system is displaced along an optical axis direction on the basis of a measurement result of said measuring means, to change the angular distribution of the illumination light entering the projection optical system, with magnification with respect to the optical axis center.

These and other objects, features and advantages of the present invention will become more apparent upon a consideration of the following description of the preferred embodiments of the present invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic view of a projection exposure apparatus according to an embodiment of the present invention.

5                Figure 2 is a schematic view for explaining deviation of magnification telecentricity.

Figure 3 is a schematic view for explaining deviation of on-axis telecentricity.

10              Figure 4 is a schematic view for explaining measurement of angular distribution of illumination light, in an embodiment of the present invention.

Figure 5 is a schematic view for explaining measurement of an angular distribution of illumination light, in another embodiment of the present invention.

15              Figure 6 is a schematic view for explaining a magnification telecentricity correcting mechanism.

Figure 7 is a flow chart for explaining the procedure of correction of magnification telecentricity, in an embodiment of the present invention.

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Figure 8 is a schematic view for explaining an on-axis telecentricity correcting mechanism, in an embodiment of the present invention.

25              Figure 9 is a flow chart for explaining the procedure of correction of on-axis telecentricity, in an embodiment of the present invention.

Figure 10 is a flow chart for explaining the

procedure wherein corrections for magnification telecentricity, on-axis telecentricity and illuminance non-uniformness are performed in series.

5            Figures 11A and 11B are schematic views, respectively, for explaining an example of illuminance non-uniformness correcting means with an optical filter.

10           Figure 12 is a schematic view for explaining an example of illuminance non-uniformness correcting means for [used] use in a scanning exposure apparatus.

            Figure 13 is a flow chart of device manufacturing processes, in an embodiment of the present invention.

15           Figure 14 is a flow chart of a wafer process in the procedure of Figure 13.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

20           Figure 1 is a schematic view of a first embodiment of the present invention. In this embodiment, the invention is applied to a projection exposure apparatus of a step-and-repeat type or step and-scan type for a lithographic process of submicron order or quartermicron order.

25           Denoted in the drawing at 1 is a light emitting tube of a light source, such as an Hg lamp, for example. It has a high-luminance light emitting portion 1a which emits ultraviolet rays or deep

30

ultraviolet rays. The light emitting portion 1a is disposed at or adjacent a first focal point of an elliptical mirror 2.

5 Denoted at 3 is a cold mirror having a multilayered film, which serves to transmit most of infrared light but to reflect most of ultraviolet light. In association with this cold mirror 3, the elliptical mirror 2 functions to form an image (light source image) 1b of the light emitting portion 1a, at  
10 or adjacent its second focal point 4.

Denoted at 5 is an optical system which comprises a condenser lens, a collimator lens and/or a zoom lens, for example. It serves in association with an optical system 6 to image the light source image  
15 1b, formed at or adjacent the second focal point 4 of the elliptical mirror 2, upon a light entrance surface 7a of an optical integrator 7. The optical system 6 is made tiltable and movable in a direction orthogonal to the optical axis, or mountable/demountable, by  
20 means of an optical system driving mechanism 34.

The optical integrator 7 comprises a plurality of small lenses having a rectangular shape in section and being disposed in a two-dimensional array at a predetermined pitch. It serves to produce  
25 secondary light sources adjacent its light exit surface 7b. Adjacent this light exit surface 7b of the optical integrator 7, there is a stop mechanism 8

having plural stop members 8a and 8b. Stop driving mechanism 33 serves to change the stop in the stop mechanism, to be placed on the optical path, by which the size and shape of the secondary light sources can be changed.

In this embodiment, stop members having different aperture shapes are selectively used in accordance with the shape of a pattern of a reticle 14 used, whereby the light intensity distribution to be produced at a pupil plane 17 of a projection optical system 16 is selectively changed. Details are discussed in Japanese Laid-Open Patent Application, Laid-Open No. 47626/1993 or No. 47640/1993.

Denoted at 9 is a lens element (optical element) which can be moved along the optical axis direction by a driving mechanism 32 so as to change the angular distribution of illumination light (angular light quantity distribution of illumination light, illuminating a certain point on the reticle 14 surface), with magnification with respect to the optical axis center (i.e., in accordance with the distance of the certain point on the reticle 14 surface to the optical axis of the projection optical system 16).

Denoted at 10 is a condenser lens which serves to superposedly and uniformly illuminate the surface of a masking blade 11 with light beams emitted

from the secondary light sources adjacent the light exit surface 7b of the optical integrator 7. The masking blade 11 comprises a plurality of movable light blocking plates which can be moved by a masking blade driving mechanism 31 to variably define a desired aperture shape, by which the illumination range on the reticle 14 surface is adjusted.

Denoted at 13 is an imaging lens which cooperates with a mirror 12 to project the aperture shape of the masking blade 11 upon the reticle 14 surface, whereby a predetermined region on the reticle 14 surface can be illuminated uniformly. The reticle 14 is held by a reticle stage 15.

The projection optical system (projection lens) 16 serves to project a pattern on the reticle 14 surface onto a wafer (substrate) in reduced scale. Denoted at 17 is a pupil of the projection optical system, and denoted at 18 is a wafer (substrate) onto which the circuit pattern of the reticle 14 is projected and transferred. Denoted at 19 is a wafer chuck for holding the wafer 18 and being movable along the optical axis direction. Denoted at 20 is an X-Y stage for holding the wafer chuck 19 and being movable two-dimensionally along a plane orthogonal to the optical axis. Denoted at 21 is a base table on which the projection lens 16 and the X-Y stage are mounted.

For the operation to be described later, the

X-Y stage 20 is arranged to be movable upwardly and downwardly along the optical axis direction, by an amount not less than a predetermined amount.

5 In the optical arrangement of this embodiment, the light emitting portion 1a, the second focal point 4, the light entrance surface 7a of the optical integrator 7, the masking blade 11, the reticle 14 and the wafer 18 surface are placed in an optically conjugate relation with each other. Also,  
10 the stop of the stop mechanism 8 and the pupil plane 17 of the projection optical system 16 are placed approximately in a conjugate relation with each other.

Denoted at 22 and 23 are components of a surface position detecting system for detecting the position (level) of the surface of the wafer 18 with  
15 respect to the optical axis direction. Here, denoted at 22 is an illumination system for illuminating the wafer 18, and denoted at 23 is a light receiving system for receiving reflection light from the wafer  
20 18 surface and for producing a signal corresponding to the position of the wafer 18. Denoted at 28 is a control device for controlling the illumination system 22 and the light receiving system 23.

Denoted at 25 is a reflection mirror fixedly  
25 mounted on the X-Y stage 20, and denoted at 26 is a laser interferometer for projecting laser light to the reflection surface of the mirror 25 and for detecting

the amount of displacement of the X-Y stage 20.  
Denoted at 27 is a driving system for controlling  
movement of the X-Y stage on the basis of an output  
from the laser interferometer 26.

5                   The driving system 27 receives surface  
position information about the surface level of the  
wafer 18, via the control device 28, and operates to  
move the wafer chuck 19 in the optical axis direction  
so that the wafer 18 surface is registered with the  
10                  imaging plane of the projection lens system 16 where  
the device pattern of the reticle 14 is imaged.

                  Denoted at 24 is a detector (such as an  
illuminomitor or a sensor) which is one of the  
components of measuring means for detecting angular  
15                  distribution and illuminance distribution of  
illumination light on the wafer 18 surface. It serves  
to receive illumination light while moving in the  
illumination field region with the motion of the X-Y  
stage 20, and to supply a signal corresponding to its  
20                  output to a detecting system 29.

                  Denoted at 30 is a main control for  
controlling various elements 27, 28, 29, 31, 32, 33  
and 34. Information from the detecting system 29 is  
supplied to this main control 30. In this embodiment,  
25                  the members disposed from the light source 1 to the  
reticle 14 serve as components which provide an  
illumination optical system.



The projection optical system of this embodiment has a function for correcting changes, as below, independently from each other which might be produced when the illumination condition is changed:

5                   a) Deviation of magnification telecentricity attributable to illumination light entering the projection optical system;

                  b) Deviation of on-axis telecentricity attributable to illumination light entering the  
10 projection optical system; and

                  c) Change in illuminance distribution upon a surface to be illuminated.

In the projection exposure apparatus of this embodiment, the lens element 19 disposed between the  
15 optical integrator 7 and the masking means 11 for regulating the illumination region can be moved, such that, substantially without changing any other performance of the illumination optical system, the angular distribution of illumination light which  
20 illuminates a certain point on the reticle 14 surface and enters the projection optical system can be changed with magnification with respect to the optical axis center (i.e., in accordance with the distance (object height) of the certain point on the reticle 14  
25 surface to the optical axis), whereby correction of magnification telecentricity is performed.

Also, as regards the deviation of on-axis

telecentricity, the optical system 6 disposed at the light source 1 side of the optical integrator 7 can be adjusted or inserted/demounted, by which the incidence angle of light entering the optical integrator 7 can be made variable. Thus, by tilting illumination light rays entering the projection optical system in the same direction, the on-axis telecentricity deviation can be corrected.

In this embodiment, the angular distribution of rays of illumination light from various points on the reticle 14 surface is measured by the measuring means 24. On the basis of the result of measurement, any deviation of magnification telecentricity or on axis telecentricity is corrected. Additionally, any illuminance non-uniformness caused in response to displacement of the optical element for correction of the magnification telecentricity and/or on-axis telecentricity, is corrected by means of a correcting mechanism separate from the correcting means for the magnification telecentricity and on-axis telecentricity.

Now, measurement of angular distribution of illumination light, illuminating a certain point on the reticle 14 surface and emitting from the projection optical system 16, by use of measuring means will be explained. The angular distribution of illumination light, illuminating a certain point on

the reticle 14 surface and entering the projection optical system 16, can be detected from the angular distribution of illumination light emitting from the projection optical system 16 and the magnification of the projection optical system 16, for example.

A first example of measuring the angular distribution of illumination light will now be described. When, for example, the angular distribution of illumination light at the center of a picture field (i.e., optical axis La position) is to be measured, the opening defined by the masking blade 11 is restricted by the masking blade actuating means 31 so that small illumination light passes only the optical axis La position. Here, as shown in Figure 4, the detector 24 is moved to the position substantially on the optical axis La and, also, it is placed below the wafer surface position 18a (to be assumed by the wafer practically) along the optical axis La direction by a predetermined distance. Only the illumination light as restricted by the masking blade 11 is imaged once upon the wafer surface position 18a and, then, the light impinges on the detector 24 while reflecting or maintaining the irradiation angle. The light intensity is measured by the detector 24 while moving the X-Y stage two-dimensionally. The results of measurement are then plotted two-dimensionally, whereby measurement of the angular distribution of

illumination light is accomplished.

In a case where the angular distribution of illumination light at any point on the wafer surface position 18a other than the optical axis position is to be measured, a small opening may be defined by using the masking blade 11 at a position on the masking blade plane corresponding to the point to be measured. Also, the X-Y stage 20 may be moved two-dimensionally so that the detector 24 position is placed at the measurement position and below the wafer surface position by a predetermined distance. Then, the measurement may be performed.

Any other method may be used, for example, a method using a CCD (image pickup device) for the detector 24, or a method in which the angular distribution of illumination light is discriminated by using a combination of a CCD and a light blocking plate having a pinhole, to be placed on the wafer surface. A method as disclosed in Japanese Patent Application No. 254386/1997 may be used.

A second example for measuring the angular distribution of illumination light will now be described.

In this example, as shown in Figure 5, the reticle 14 is provided with a reticle pattern (mark) of small openings. Denoted at 51 is a detector which is disposed adjacent the wafer 18 surface and detects

the position of an image of the reticle pattern, on the basis of the quantity of light incident thereon. More specifically, the detector 51 serves to detect the quantity of light passing through the reticle pattern (mark) of small openings, formed on the reticle 14, and then impinging on the wafer 18, by which the position of the pattern image is measured.

While defocusing the detector 51 in the optical axis La direction together with the X-Y stage 20, the position of the image is detected sequentially. From the shift of the image position with the defocusing, any deviation of telecentricity of the projection optical system 16 is detected.

Now, a third example of measuring the angular distribution of illumination light will be described.

A reticle pattern is printed by projection exposure on a wafer having a photosensitive material such as a resist applied thereto. In this operation, exposures of shots are performed while changing the focus sequentially by a predetermined amount. Then, a development process is performed to the exposed wafer and, subsequently, by using an SEM (scanning electron microscope), for example, positions of images of the pattern printed with different focus states are observed and compared with each other. From the amount of shift between these images in different focus states, any deviation of telecentricity of the

projection optical system 16 is detected.

The measurement may be performed such as described above, and deviation may occur in the projection optical system 16 in respect to magnification and on-axis telecentricity.

Particularly, in many projection exposure apparatuses, positions of components of an illumination system are adjusted so that it provides illumination light with an angular characteristic best for a certain standard illumination mode A. However, when different illumination modes are used, since the optical paths in these modes are different, the angular characteristic or non-uniformness of an anti-reflection film of an optical element or the effect of eccentricity of the lens system differs. Therefore, when the illumination mode A is changed to a different illumination mode B (such as for oblique incidence illumination or smaller  $\sigma$  value), the components of the illumination system, if they are unchanged as in the illumination mode A, do not always provide illumination light with a proper angle.

Referring now to Figure 6, an example of correction of deviation in magnification telecentricity will be described.

There is a mechanism for moving a lens element 9 in the optical axis direction, by which magnification telecentricity (i.e., incidence angles

of chief rays corresponding to image heights, with respect to the image plane) changes substantially linearly. The structure is so arranged that, while the magnification telecentricity changes with the driving mechanism, the remaining performance (e.g., illumination NA or uniformness of effective light source) is substantially unchanged. Thus, the lens element 9 is moved to correct deviation of magnification telecentricity, independently of the other performance. Figure 6, in part (A), illustrates a change in magnification telecentricity with motion of the lens element 9, and, in part (B), it illustrates variation of magnification telecentricity.

Figure 7 is a flow chart for explaining the procedure for correcting deviation of magnification telecentricity in this embodiment.

First, by using the mechanism described hereinbefore, the angular distribution of illumination light entering the projection optical system 16 is measured (step 101). On the basis of the amount of deviation of magnification telecentricity as detected by the detecting system 29, the control device 30 discriminates the necessity of correction (step 102) and, if it is necessary, calculates the direction and amount of movement of the lens element 9 to be made (step 103). Then, it applies a signal, corresponding to the movement direction and movement amount, to the

lens system driving mechanism 32. On the basis of this signal, the lens system driving mechanism 32 moves the lens element 9 along the optical axis, in a corresponding direction and by a corresponding amount (step 104). After this driving, angular distribution of illumination light is measured again (step 105). If deviation of magnification telecentricity is within a tolerable range (106), the procedure goes to the next step. If not so, the operation described above is repeated, until the deviation comes into the tolerable range.

Referring now to Figure 8, correction of deviation of on-axis telecentricity will be described.

If there is deviation of on-axis telecentricity such as illustrated in Figure 8 in part (A), in order to correct the direction of incidence light, since the wafer 18 surface and the light entrance surface 7a of the optical integrator are optically conjugate with each other, the direction of light entering the optical integrator may be changed.

In this embodiment, this is accomplished by tilting or moving the optical system 6 (as changing means) in a direction orthogonal to the optical axis, or by inserting/demounting it (part (B) in Figure 8).

Figure 9 is a flow chart for explaining the procedure of correcting deviation of on-axis telecentricity, in this embodiment. An example



disclosed in Japanese Patent Application No.  
254386/1997 may be used.

In the flow chart of Figure 9, first, the  
angular distribution of illumination light entering  
the projection optical system 16 is measured (step  
201). On the basis of the amount of deviation of on-  
axis telecentricity as detected by the detecting  
system 29, the control device 30 discriminates the  
necessity of correction (step 202) and, if it is  
necessary, calculates the direction and amount of  
movement of the optical system 6 to be made (step  
203). Then, it applies a signal, corresponding to the  
movement direction and movement amount, to the lens  
system driving mechanism 34. On the basis of this  
signal, the lens system driving mechanism 34 moves the  
optical system 6 in a corresponding direction and by a  
corresponding amount (step 204). After this driving,  
angular distribution of illumination light is measured  
again (step 205). If deviation of on-axis  
telecentricity is within a tolerable range (206), the  
procedure goes to the next step. If not so, the  
operation described above is repeated, until the  
deviation comes into the tolerable range.

When the angular distribution of  
illumination light is measured, there may be a case  
where both the magnification telecentricity and on-axis  
telecentricity are deviated. In such cases, deviation

in incidence angle of illumination light may be decomposed into a magnification telecentricity component and an on-axis telecentricity component. Then, correction may be made to these deviations, on  
5 the basis of combined procedures described with reference to Figures 7 and 9. Decomposition of a measured value on telecentricity deviation into a magnification telecentricity deviation component and an on-axis telecentricity deviation component, may be made  
10 easily by calculation based on a least square method, for example, using functions representing the magnification component and the shift component, for example.

After the angular distribution of  
15 illumination light is made proper (in a tolerable range), the detector 24 is used to measure the illuminance non-uniformness so as to check whether a standard level is satisfied or not. This is because, due to movement of the lens system 6, the illuminance  
20 distribution on the light entrance surface of the optical integrator 7 might have changed, causing degradation of illuminance distribution on the surface to be illuminated (i.e., reticle 14 surface or wafer 18 surface). If the illuminance non-uniformness  
25 satisfies the standard, the procedure is finished. If the illuminance non-uniformness does not satisfy the standard, the control device 30 performs calculation

on the basis of the measured value, and then the illuminance non-uniformness correcting means corrects the non-uniformness. Thereafter, illuminance non-uniformness measurement is made again. If it satisfies the standard value, the procedure is finished. If not, the procedure for correcting illuminance non-uniformness is repeated, until the standard is satisfied.

As regards the illuminance non-uniformness correcting means, it may be based on a method in which an optical element of a wedged shape with a coating film having different transmission factors with different incidence angles of incident light or an inclined parallel flat plate as disclosed in Japanese Laid-Open Patent Application, Laid-Open No. 190969/1997 is incorporated into the stop mechanism 8, integrally with its stop member. [In] On that occasion, in response to a change of illumination mode, also the illuminance non-uniformness correcting effect can be changed. Thus, by setting the illuminance non-uniformness correcting optical element mounted on the stop, in optimum, the illuminance non-uniformness can be optimized.

Another example of illuminance non-uniformness correcting means may be use of an optical filter 61 (Figure 11) such as an ND filter disposed at the light entrance surface 7a of the optical

integrator 7, as disclosed in Japanese Patent Application No. 126335/1997, wherein correction is made by moving the optical filter 61. By moving this optical filter 61 to an optimum position when the illumination mode is changed, the illuminance non-uniformness can be minimized.

The examples of illuminance non-uniformness correcting means described above are for [used] use in a step-and-repeat type projection exposure apparatus. For a step-and-scan type scanning projection exposure apparatus, on the other hand, slit means having a variable slit width with respect to a scan direction may be provided adjacent the masking blade 11 which is to be scaningly moved in synchronism with the reticle stage 15 and the X-Y stage 20. Illuminance non-uniformness can be corrected by it. Figure 12 is a schematic view for explaining correction of illuminance non-uniformness in accordance with this method. If  $I_0$  and  $I_1$  denote the integrated exposure amounts, by scan, at certain slit positions and  $D_0$  and  $D_1$  denote the widths of the variable slit 71 corresponding to the slit positions, the following relation should be satisfied:

$$I_0 \times D_0 = I_1 \times D_1$$

When this is accomplished, then the integrated exposure amount on the surface being illuminated as provided by the scan, that is, the illuminance

distribution, can be made uniform.

Figure 10 is a flow chart for explaining the procedure for correcting magnification telecentricity and on-axis telecentricity in series as well as the procedure of correcting illuminance non-uniformness caused by the correction.

While the embodiments described above use a Hg lamp as the light source for producing an effective light source, the effective light source may be produced by using a laser, for example, without any functional modification to the described embodiments.

Next, an embodiment of a semiconductor device manufacturing method which uses a projection exposure apparatus according to any one of the preceding embodiments, will be explained.

Figure 13 is a flow chart of a procedure for the manufacture of microdevices such as semiconductor chips (e.g., ICs or LSIs), liquid crystal panels, or CCDs, for example.

Step 1 is a design process for designing a circuit of a semiconductor device. Step 2 is a process for making a mask on the basis of the circuit pattern design. Step 3 is a process for preparing a wafer by using a material such as silicon. Step 4 is a wafer process which is called a pre-process wherein, by using the so prepared mask and wafer, circuits are practically formed on the wafer through lithography.

Step 5 subsequent to this is an assembling step which is called a post-process wherein the wafer having been processed by step 4 is formed into semiconductor chips. This step includes an assembling (dicing and bonding) process and a packaging (chip sealing) process. Step 6 is an inspection step wherein an operation check, a durability check and so on for the semiconductor devices provided by step 5, are carried out. With these processes, semiconductor devices are completed and they are shipped (step 7).

Figure 14 is a flow chart showing details of the wafer process.

Step 11 is an oxidation process for oxidizing the surface of a wafer. Step 12 is a CVD process for forming an insulating film on the wafer surface. Step 13 is an electrode forming process for forming electrodes upon the wafer by vapor deposition. Step 14 is an ion implanting process for implanting ions to the wafer. Step 15 is a resist process for applying a resist (photosensitive material) to the wafer. Step 16 is an exposure process for printing, by exposure, the circuit pattern of the mask on the wafer through the exposure apparatus described above. Step 17 is a developing process for developing the exposed wafer. Step 18 is an etching process for removing portions other than the developed resist image. Step 19 is a resist separation process for separating the

resist material remaining on the wafer after being subjected to the etching process. By repeating these processes, circuit patterns are superposedly formed on the wafer.

5                   With these processes, high density microdevices can be manufactured.

                  In accordance with the embodiments of the present invention described hereinbefore, the components are specified as described above, by which  
10                   deviation of magnification telecentricity and deviation of on-axis telecentricity to be produced when the illumination mode or illumination condition is changed, can be corrected independently of each other. As a result, the illumination light can be  
15                   supplied with optimum angle. Thus, a projection exposure apparatus and a device manufacturing method using the same, with which a pattern image of very high resolution is attainable, can be accomplished.

                  An example of correcting means may use the  
20                   function for measuring the angular distribution of illumination light, and feedback control may be performed on the basis of the result of measurement.

                  Any non-uniformness of illuminance to be produced as a result of correction of telecentricity  
25                   deviation can be corrected by using a mechanism for correcting it independently of the telecentricity correcting function. This accomplishes a projection exposure apparatus and a device manufacturing method

using the same, with which the illuminance uniformness on the surface to be illuminated can be maintained and various reticle patterns can be projected on a wafer surface stably with high resolution.

5                   Angular distribution of exposure light entering a projection optical system or of a deviation of incidence angle of exposure light may be measured and, on the basis of the result of measurement, an optical element in a portion of an illumination system  
10 may be moved or inserted/demounted. This enables independent correction of deviations of magnification telecentricity and on-axis telecentricity regardless of various changes of illumination mode or illumination condition, and also it enables correction  
15 of illuminance distribution to be produced by the correction. Therefore, a projection exposure apparatus or a device manufacturing method using the same, with which various reticle patterns can be projected on a wafer stably with high resolution, can  
20 be accomplished.

                  While the invention has been described with reference to the structures disclosed herein, it is not confined to the details set forth and this application is intended to cover such modifications or  
25 changes as may come within the purposes of the improvements or the scope of the following claims.